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Aerospace Flywheel Technology Development for IPACS Applications

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ABSTRACT

The National Aeronautics and Space Administration and the Air Force Research Laboratory are cooperating under a space act agreement to sponsor the research and development of aerospace flywheel technologies to address mutual future mission needs. Flywheel technology offers significantly enhanced capability or is an enabling technology. Generally these missions are for energy storage and/or integrated power and attitude control systems (IPACS) for mid-to-large satellites in low earth orbit. These missions require significant energy storage as well as a CMG or reaction wheel function for attitude control. A summary description of the NASA and AFRL flywheel technology development programs is provided, followed by specific descriptions of the development plans for integrated flywheel system tests for IPACS applications utilizing both fixed and actuated flywheel units. These flywheel system development tests will be conducted at facilities at AFRL and NASA GRC and include participation by industry participants Honeywell and Lockheed Martin.

Keywords: Flywheel, IPACS, Energy Storage, Attitude Control, Satellite

INTRODUCTION

The National Aeronautics and Space Administration and the Air Force Research Laboratory are cooperating under a space act agreement to sponsor the research and development of aerospace flywheel technologies to address mutual future mission needs. For some missions, flywheel technology offers significantly enhanced capability or is an enabling technology. Generally these missions are for energy storage and/or integrated power and attitude control systems (IPACS) for mid-to-large satellites in low earth orbit. These missions require significant energy storage as well as a CMG or reaction wheel function for attitude control.

In order to address these mission needs and demonstrate the readiness of flywheel technology, integrated flywheel system development and operational demonstrations are needed. Three major development and test activities that will begin to address the system integration questions are in progress within the NASA and AFRL flywheel programs. These development activities are the subject of this paper. A summary description of the NASA and AFRL flywheel technology development programs is provided, followed by specific descriptions of the development plans for integrated flywheel system tests for IPACS applications.

PROGRAM CONTENT DESCRIPTION

A summary description of the NASA and AFRL flywheel technology development programs is provided below.

NASA Program

The Aerospace Flywheel Technology Program is funded by the NASA Headquarters Code R Cross-Enterprise Technology Development Program/Space Base Program and managed by Glenn Research Center. The objectives of this program are to develop advanced aerospace flywheel component and system technologies to meet NASA's long term mission needs. Flywheel technology addresses mission needs for energy storage, integrated power and attitude control, and power peaking.

The near term focus of the program is on "Century" class flywheels with energy storage capacity in the hundreds of watt-hours (300-700) for application to mid-sized satellites. In addition, longer term development of flywheels for small satellite applications is also in progress at energy capacities less than 100 watt-hours. Flywheel technology goals are defined by the metrics in Table 1. Flywheel technology offers significant performance advantages for energy storage and IPACS in low Earth orbit applications such as ISS and Earth Sciences. Other NASA applications that require power peaking such as advanced launch vehicles and launch systems are also areas where flywheels can offer significant performance advantages.

Table 1. Flywheel Technology Program Metrics

Metric	Goal
Usable System Specific Energy	Near term > 45 Whr/Kg Long Term >200 Whr/Kg
Cycle Life	> 75,000 cycles
Round Trip Efficiency	> 90%
System Cost Reductions	> 25%

While flywheel technology development is ongoing at NASA GRC, there is also a system prototype development project at GRC funded by NASA Headquarters, Code M for the International Space Station (ISS) called the Flywheel Energy Storage System (FESS) Project. This project is specifically developing a prototype flywheel battery for possible use as replacements for the ISS electro-chemical batteries. If development is successful, a flywheel battery could fly on ISS as early as 2005.

The flywheel technology program supports research and development in three areas: flywheel systems, component technologies, and rotor safe-life technologies. In addition, this program leverages other programs such as the AFRL FACETS Program, the FESS Project, the Commercial Space Centers at Auburn and Texas A&M Universities, NASA NRA's and SBIR's, support from NASA Code Q and GRC/Army Research Lab aeronautics and internal programs. The NASA CETDP NRA contract with Lockheed Martin for the development of the COMET Flywheel System™, which is described below, is a key flywheel system integration development task.

The flywheel technology program conducts research over a broad spectrum of component technologies. Table 2 summarizes these activities, including leveraged program tasks.

Table 2. Flywheel Technology Program Research

Component	Task	Source
Magnetic Bearings	Advanced Bearing Control	GRC, Texas A&M
	Fault Tolerant Actuators and Optimized Design	Texas A&M
	Health Monitoring	Texas A&M, UT-CEM
	Passive Bearings	GRC, Foster-Miller
Power Train	Optimized Motor/Gen Control	GRC, Penn State
	Advanced Motor/Generator	GRC
	High Speed Concepts	GRC, Penn State
Composite Rotors	Rims and hubs	Auburn U., UT-CEM
	Rotor design optimization	GRC, Auburn U., UT-CEM
	Material Characterization	GRC, UT-CEM, FESI
	Rotor Fatigue Testing	GRC, CNRC
	Rotor NDE	GRC
	Standardized Certification Process	GRC, AFRL, Aerospace Corp.

A focal point for the flywheel component and system research and development is the flywheel testbed at GRC. This will allow the demonstration in a systems environment of advanced component and system technologies developed by the flywheel program to meet performance metrics and NASA mission needs. The flywheel testbed facility is operational and a flywheel module development unit is currently under test. This test program will be described below.

AFRL Program

The capstone of flywheel development at the Air Force Research Lab (AFRL) Space Vehicles Directorate will be the Flywheel Attitude Control, Energy Transmission and Storage ground demonstration on the Advanced STRuctures Experiment (ASTREX) test-bed at the AFRL facility in Albuquerque, NM (Kirtland AFB), Figure 1. This testing represents the first three degree-of-freedom spacecraft simulator demonstration of simultaneous energy storage and attitude control using flywheels.

Figure 1 ASTREX Test-Bed at AFRL

The main difference between the FACETS ground demonstration and the other flywheel-based IPACS demonstrations mentioned in this paper is that the IPACS units in this case will be gimbaled. It is well-known that gimbaled wheels, or control moment gyros (CMGs), are used for attitude control in spacecraft applications requiring large control torques. Using gimbaled wheels provides the maximum flexibility in testing since the flywheel units can be operated in either a locked-gimbal or controlled-gimbal mode to represent both reaction wheel or CMG attitude control actuation. The mounting scheme on ASTREX will also be designed to maximize flexibility in the testing of multiple wheel configurations.

The primary purpose of this effort is to verify that full exploitation of the enormous benefits of flywheels for spacecraft applications is realized in the combined functionality of energy storage and momentum management/attitude control. The FACETS ground demonstration will actually be the culmination of four related efforts:

1. A multi-phase development effort with Honeywell, Inc., Tempe, AZ, to design, develop and individually test IPACS units, Figure 2, for use in FACETS,
2. In-house basic controls research at AFRL focused on the development of practical control algorithms for performing simultaneous energy storage and attitude control with gimbaled wheels as well as control of the magnetic bearings,
3. An international cooperative effort with the Canadian Space Agency to verify that the composite rotors in the Honeywell IPACS units have sufficient cycle life for the demonstration, and
4. Facility development at AFRL, including modification of the ASTREX structure, upgrades to the ASTREX test-bed and setting up the ASTREX high-bay and control room to control and monitor the FACETS demonstration testing.

Figure 2 Honeywell IPACS Unit

The development activities at Honeywell will continue under a Phase II effort beginning in Spring, 2001, aimed at completing the full operational testing of the Phase I IPACS unit and upgrading the unit with housing and electronics suitable for testing on ASTREX. This upgrade will also insure that the Phase II IPACS units have a 'path-to-flight' so that this development will lead to flight-quality flywheel hardware for use in satellite applications.

Development Program Description

There are three development activities currently in progress at NASA and AFRL to demonstrate integrated flywheel operation in IPACS configurations. The AFRL activity is focused on demonstrating flywheels for a gimbaled CMG and energy storage type application. The NASA activities at GRC and Lockheed Martin address the lower momentum requirements more typical of NASA missions and are focused on the use of fixed flywheel configurations for energy storage and momentum control. These development activities are described below.

AFRL FACETS Development

The ASTREX facility, located in a dedicated high-bay facility within the Space Vehicles directorate at the AFRL, Kirtland AFB, New Mexico Phillips Research Site, will be the focal point of FACETS development. ASTREX is a spacecraft structure simulator mounted on a spherical air bearing, which gives it the 3 degree-of-freedom motion desired for attitude control testing. ASTREX also has additional sensors and actuators (accelerometers, angular encoders, thrusters, etc.) that will aid in the testing and verification of the attitude control function of FACETS. This will be performed simultaneously with the energy storage and power transmission capability. The ASTREX test-bed was originally designed to investigate structural disturbances caused by attitude control actuation and explore methods for mitigating these effects. Because of this, ASTREX also provides the opportunity to investigate and control structural disturbances influenced by the simultaneous energy storage and attitude control functionality of FACETS.

The test plan for the FACETS ground demonstration is built around the primary objective of demonstrating simultaneous energy storage and attitude control capability for both gimbal-locked and gimbal-controlled modes of operation. The testing will be conducted in three main phases:

1. Integration/Calibration Testing
2. Closed-loop Testing
3. Advanced Control Testing

Integration/Calibration Testing. This phase of the testing will focus on integrating the IPACS hardware with the mechanical, electrical and control systems of ASTREX. It will also include calibration of the sensors and actuators (ASTREX and IPACS) to compensate for bias, misalignments and noise. This phase will rely heavily on the system simulation model, using it for hardware-in-loop testing of hardware in place on ASTREX. Test sequences in this phase will include open loop slewing of the ASTREX structure to verify sensor, actuator and system-level operation.

Closed-Loop Testing.. This phase represents the crux of the FACETS ground demonstration. It is in this phase that the loop will be closed on the system level simultaneous energy storage and attitude control algorithm. Test sequences will consist of attitude hold, long duration attitude hold, IPACS hardware desaturation (returning gimbal angles to 'zero' position without introducing torque disturbances), characterization of attitude stability and long term accuracy, and target tracking maneuvers. Energy storage functionality will be tested under several scenarios including average (housekeeping) satellite power levels and worst case peak loading representative of high power, short duty cycle applications.

Advanced Control Testing. The objective of this phase is to improve performance of nominal closed-loop control tested in the previous phase by taking into account lessons learned during that testing. This may involve hardware and software reconfiguration and use of more advanced control methodologies, such as incorporation of singularity avoidance. The test sequence is open-ended since potential areas of improvement will be unknown prior to the nominal closed-loop testing.

NASA Testbed Development

The flywheel testbed at NASA GRC will be used to demonstrate a single axis attitude control and energy storage system (ACESE) and will be used to test prototype electronics for the Flywheel Energy Storage System (FESS) on the International Space Station (ISS). The layout of the test cell, control room, and facilities support equipment room is shown in Figure 3. A picture of the control room is shown in Figure 4.

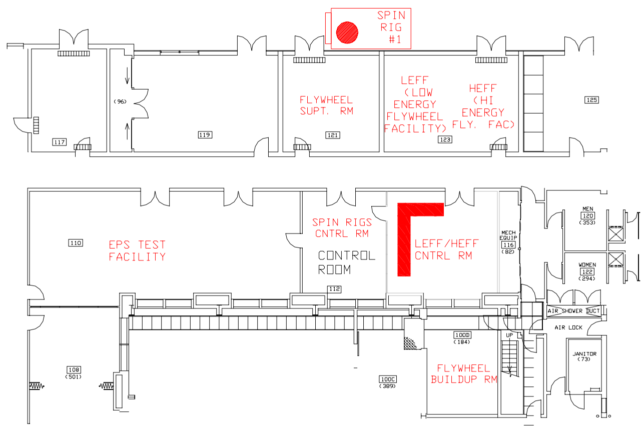


Figure 3. Flywheel Testbed Facilities – Building 333, NASA GRC

Figure 4. Flywheel Testbed Control Room

The hardware configuration for the ACESE experiment consists of two flywheel modules with parallel spin axis vertically mounted on an air bearing table. The electronics and controls to support the magnetic bearing and motor/generator systems and provided overall system control are a combination of COTS and brassboard hardware with rapid prototype software written in Simulink. A system layout is shown in Figure 5.

Each flywheel module stores 350 W·hrs and has a rotor inertia of .066 kg·m^2. The motor/generator can charge or discharge at 3 kW with a torque of 1.43 N·m. Detailed specifications are shown in Table 3. The rotor is suspended with active magnetic bearings and has a rolling element touchdown bearing for off nominal conditions. The flywheel module housing provides the vacuum enclosure and mounting locations for the stator components. The two flywheel modules are shown in Figure 6.

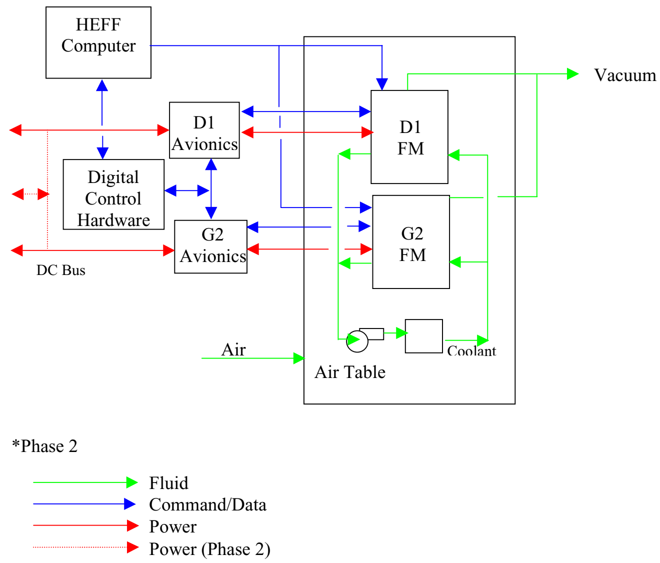
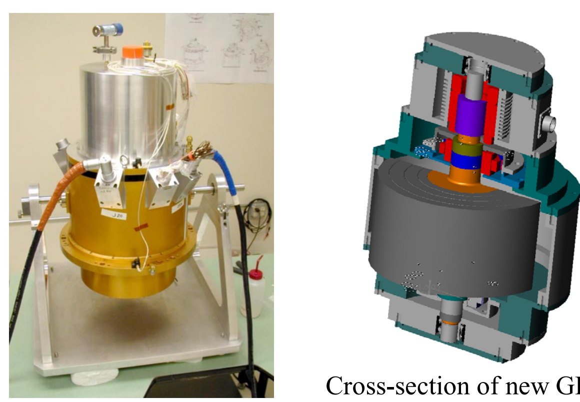


Figure 5. ACESE System Schematic

Table 3. ACESE Flywheel Module Characteristics

Characteristic	Specification
Useable Energy Storage	320 W-Hrs
Charge/Dischg Power	3000 W
Operating Speed Ratio	3/1
Maximum Speed	60,000 RPM
Motor/Generator	PM Sync, 2-pole, 3-phase Y connected
DC Bus Voltage	130 V
Magnetic bearings	Homopolar PM bias, 4-pole



Development Unit #1

Cross-section of new GRC Design, G2

Figure 6. Development Units at GRC

The ACESE experiment has three phases:

1. Demonstrate two flywheel modules operating on a lightly constrained mounting system (air bearing table),
2. Demonstrate momentum and energy control in charge mode with the flywheels on separate power buses, and
3. Demonstrate full momentum and energy control in charge and discharge on a single power bus.

In the first phase, the operational demonstration of a magnetically suspended flywheel module functioning on an air table will be used to verify an analytical modeling effort which is exploring the effect of mount stiffness on magnetic bearing stability. In the second phase of the ACESE experiment the combined charge rate and net torque of the two flywheel modules will be controlled. This demonstration will be limited to charge mode only, since the flywheels are on separate power buses. Step response, overshoot and regulation band will be compared to analytical models. In the final phase, both flywheel modules will be run on one power bus. Charge mode will operate in the same manner as in the second phase. In discharge the controller will regulate the bus voltage and the net torque of the two-wheel system.

After completing the ACESE work, the same test hardware will support the FESS program. Brassboard and prototype avionics for the space station flywheel will be tested and debugged prior to the delivery of the FESS flywheel modules.

FESS testing will focus on efficiency measurement and control verification. The ACESE flywheel modules store 1/10 of the energy of the FESS modules. Since the normal orbit cycle can not be demonstrated with the smaller wheels, two extremes will be tested. First, the system will be run at normal charge and discharge power levels, completing an orbit cycle in nine minutes. Second, the system will be run the full ninety minutes at 1/10 power.

The synergy between the ACESE and FESS efforts have allowed NASA GRC to focus resources and provide value to each program at reduced cost.

Lockheed Martin COMET Flywheel System™ Development

Lockheed Martin in Newtown, Pennsylvania is under contract with NASA Glenn Research Center to design, build, and test a demonstration of an innovative IPACS called the COMET Flywheel System. "COMET" is an acronym for "*coordinated momentum and energy transfer*". Figure 7. shows the COMET Flywheel System integrated with the satellite power and attitude control subsystems. Typically a flywheel based IPACS uses either gimballed flywheels, or fixed-axis flywheels arrange in counter rotating pairs. In the case of counter rotating pairs, a minimum of six flywheels are required to achieve full attitude torque authority. The COMET Flywheel System uses as few as four fixed-axis flywheels arranged in a pyramid.

At the heart of system is the COMET Flywheel Logic™ used to coordinate the momentum and energy transfer from the flywheels. Each flywheel is used as a torque actuation device. The sum of torques times respective wheel speeds results in power transfer to/from the power bus (energy transfer). The vector sum of the torques results in a net torque on the spacecraft body (momentum transfer). The individual torques are coordinated so that the momentum and energy transfer meet the needs of the attitude control and electrical power subsystems.

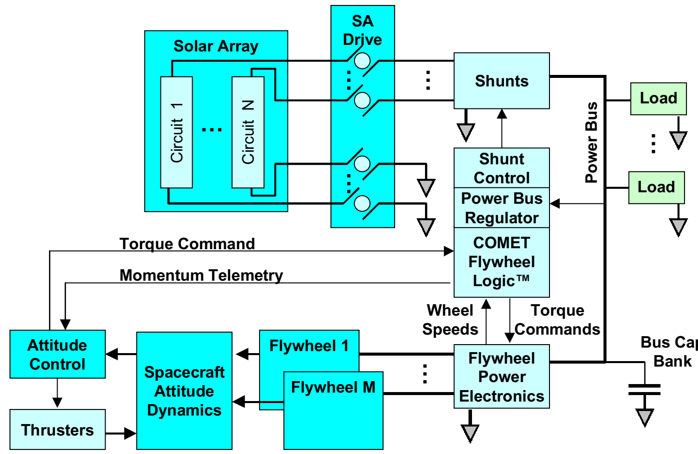


Figure 7. Integrated COMET Flywheel System™

The basic approach (Ref. 1) is to apply a torque allocation matrix to a vector composed of a power command and three-axis torque command to generate individual torque commands to the flywheels. The torque allocation matrix is derived from knowledge of the flywheel alignment and wheel speeds. The work of Ref. 1 has been augmented to include null space control to equalize the wheel speeds to the extent possible in the case that five or more wheels are used to achieve the energy and momentum requirements. Also, and more importantly, a fast wheel speed loop (Ref. 2) is incorporated to reject torque disturbances resulting from load power fluctuation coupling through mismatches between the individual flywheel power electronics.

The objective of the contract is to demonstrate feasibility of combining momentum and energy storage/transfer capabilities using the COMET Flywheel System. Three flywheels will be mounted on a force table with their spin axis in the plane of the table arranged at 120 degree intervals. Force transducers will measure the net reaction torque in two axes. Load power and attitude torque profiles will be applied and the power bus voltage and net reaction torque will be observed to validate the system operation. An important part of the program is the generation of a flywheel subsystem specification and a scalability report that shows how the designs used in the demonstration must be modified for a flight program.

The contract began in April 2001 and will end in March 2004. The first year is dedicated to trade studies and preliminary design. The second year will be dedicated to detailed design and build-up of the first of the three flywheels. During the third year the other two flywheels will be built and tested. Finally the flywheels will be integrated into the demonstration system and tested.

SUMMARY

The National Aeronautics and Space Administration and the Air Force Research Laboratory are cooperating under a space act agreement to sponsor the research and development of aerospace flywheel technologies to address mutual future mission needs. For some missions, flywheel technology offers significantly enhanced capability or is an enabling technology. Generally these missions are for energy storage and/or integrated power and attitude control systems (IPACS) for mid-to-large satellites in low earth orbit. These missions require significant energy storage as well as a CMG or reaction wheel function for attitude control.

Three major development and test activities that will begin to address the system integration questions are in progress within the NASA and AFRL flywheel programs. Development tests at Honeywell and the AFRL ASTREX Facility will address flywheel system development for CMG/energy storage type IPACS applications. Development activities at NASA GRC and Lockheed Martin will address flywheel system development for fixed flywheel IPACS applications. These development test programs, being conducted as integrated flywheel systems, will significantly advance the state of the art in flywheel applications for IPACS missions.

REFERENCES

1. Tsiotras, P., Shen, H., and Hall, C., "Satellite attitude Control and Power Tracking with Energy/Momentum Wheels", Journal of Guidance, Control, and Dynamics, Vol. 24, No. 1, January-February 2001, pp. 23-34.

2. Goodzeit, N. E., Paluszek, M. A., and Cohen, W. J., "Attitude Control System with Reaction Wheel Friction Compensation", U.S. Patent No. 5,201,833, Apr. 13, 1993.

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